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Impact of Routine Completion Angiography on the Results of Primary Carotid Endarterectomy: A Prospective Study in a Teaching Hospital CME

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KEYWORDS
Carotid endarterectomy;
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Abstract *Objective:* To assess the usefulness of completion angiography in the prevention of stroke, carotid occlusion and residual stenosis after primary carotid endarterectomy (CEA) in the setting of a teaching hospital.
Material and Methods: From January 1995 to August 2009, 1055 consecutive patients having 1179 CEAs were entered in a prospective study excluding patients with severe renal insufficiency, allergy to contrast media and patients with repeat CEA or carotid bypass. In this cohort, 552 patients (52.3%) were asymptomatic, 318 (30.2%) had a transient ischaemic attack (TIA) and 185 (17.5%) had a stroke. Routine completion angiography was obtained in all 1055 patients. The decision to perform a surgical revision was decided for any of the following defects: (1) a residual stenosis of more than 50% of the internal carotid artery (ICA) or common carotid artery (CCA) and of more than 70% of the external carotid artery (ECA), (2) any flap and (3) any intraluminal-filling defect. A postoperative duplex scan was obtained within a week after surgery and thereafter on a yearly basis. Median follow-up was 7 years.
Results: CEA was performed by a senior surgeon as first operator in 812 cases (69%) and by a trainee, with a scrubbed senior surgeon, in 367 cases (31%). Completion angiography revealed significant defects in 72 cases (6.1%) warranting revision for ECA flap ($n = 30$), thrombus in contact with the patch ($n = 7$), distal ICA flap or stenosis ($n = 20$) and CCA flap or residual plaque ($n = 15$).
Logistic regression analysis showed that total length of the carotid plaque >6 cm ($p = 0.02$, Odds ratio: 2.31; 95% confidence interval (CI) (1.21–3.72)), eversion endarterectomy of the ECA ($p = 0.01$, Odds ratio 3.41; 95%CI (2.10–5.94)) and trainee as first operator ($p = 0.02$,

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Odds ratio 2.42; 95%CI (1.81−4.23)) were independent predictors of operative defects seen on completion angiography. No complication in relation to carotid catheterisation or injection of contrast media occurred in this series.

The 30-day combined stroke and death rate was 1.5%, comparable between senior surgeons and trainees ($p = 0.60$). There was no significant difference in the combined stroke and death rate observed in patients with normal completion angiography (1.4%) compared with that of the patients with a defect corrected (2.8%) ($p = 0.28$, Odds ratio: 0.67; 95%CI (0.22−2.09)). But there was an increased incidence of postoperative TIA in the group with revision ($p = 0.001$, odds ratio: 5.8, 95%CI: 1.8−18.9).

At 7 years, the freedom rate from >50% carotid restenosis or occlusion was 87.5 ± 6.7% in patients with normal completion angiography and 92 ± 5.4% in patients, who undergo a surgical revision.

Conclusion: In a single centre, CEA with routine completion angiography resulted in good perioperative outcome. Plaque length, technique for external carotid artery (ECA) endarterectomy and trainee as first operator were independent predictors of operative defects seen on completion angiography.

Introduction

The beneficial role of carotid endarterectomy (CEA) is supported by level 1 evidence in selected asymptomatic and in symptomatic patients with severe carotid stenosis.[1−4] However, the absolute benefit of CEA is limited by the amount of surgical complications, and there is still no consensus on whether the routine use of an intra-operative completion assessment should be performed to confirm the technical adequacy of CEA.[5,6] This discrepancy is partially due to the favourable outcome of CEA even without the routine use of completion imaging,[1,3,7] and also due to the fact that certain intra- and postoperative strokes, including intracerebral bleeding, as well as hyperperfusion syndrome, are unrelated to the surgical technique. Nevertheless, many authors have shown that detection and correction of significant technical defects by an intra-operative completion study lower the risk of postoperative stroke.[8−16] The purpose of this prospective study was to evaluate the potential risk and benefit of routine completion angiography for detection of significant intra-operative defects in a prospective series of 1179 consecutive primary CEA performed within a teaching hospital.

Material and Methods

From January 1995 to August 2009, a total of 1402 carotid revascularisations for atheromatous disease were performed at our institution in 1278 patients. Patients with repeat CEA or carotid bypass, as well as patients with a contraindication to angiography because of allergy or severe renal insufficiency were excluded from this study (Fig. 1), leaving 1055 patients having 1179 primary CEA procedures with completion angiography, who were entered in a prospective study; those protocols were approved by the institutional review board of the University of Poitiers. Bilateral staged CEA procedures were performed in 124 patients. Demographics, risk factors, indications for surgery, characteristics of carotid lesions and technical details are reported in Table 1. Prior to surgery, a neurologist independently assessed all symptomatic patients. In this series, the findings of the intra-operative completion angiography were entered into a predefined database with details concerning the nature and location of the defects observed, together with the need for surgical correction, the incidence of postoperative complications and the technique used for correction. In addition, the following variables were recorded: surgeon (senior or trainee), type of CEA, patch material, shunt insertion, total length of the endarterectomy specimen measured in centimeters in the common (CCA) and internal carotid artery (ICA) and technique used on the external carotid artery (ECA) with measurement of the length of the ECA specimen.

All patients received aspirin; 977 patients (93%) received aspirin alone and 72 patients received aspirin and clopidogrel (7%); and 852 patients (80.7%) received statins at

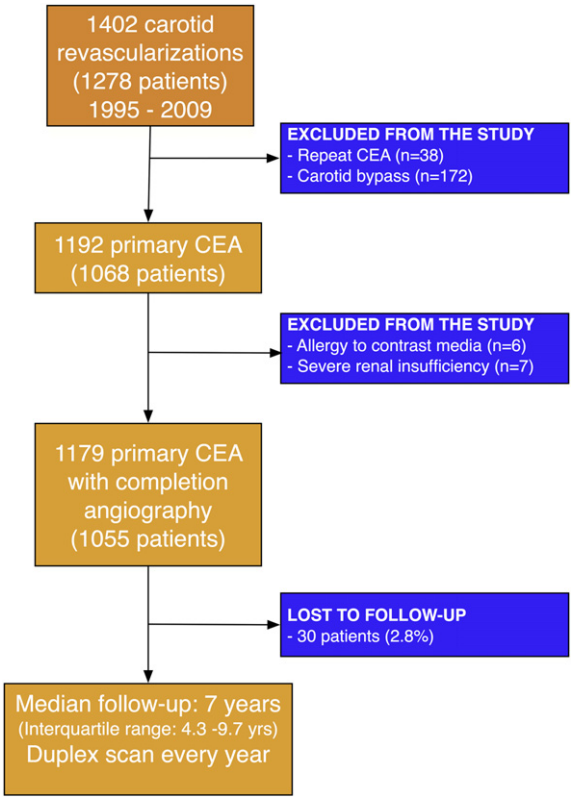

Figure 1 Flowchart of the study and follow-up status.

Table 1 Patients characteristics and risk factors in 1055 patients having 1179 carotid endarterectomies.

	N	Prevalence (%)
Age (y)		
<70	580	54.9
≥70	475	45.1
Gender		
Male	728	69.0
Female	327	31.0
Current smoker	696	65.9
Hypertension	685	64.9
Congestive heart failure	61	5.8
Coronary artery disease	221	21.0
Unstable angina	45	4.3
Peripheral arterial disease	295	27.9
Diabetes mellitus	232	22.0
Renal insufficiency	57	5.4
Surgical indications		
Transient ischemic attack	318	30.2
Stroke	185	17.5
Asymptomatic	552	52.3
First operator		
Senior vascular surgeon	812	68.8
Trainee supervised	367	31.2
Ipsilateral stenosis		
50–69%	212	17.9
70–99%	967	82.1
Contralateral stenosis		
<50%	354	30.1
50–69%	601	50.9
70–99%	224	19.0
Length of the plaque (ICA + CCA)		
<6 cm (specimen)	858	72.8
≥6 cm (specimen)	321	27.2
Length of the plaque (ECA)		
<3 cm (specimen)	1041	88.3
≥3 cm (specimen)	138	11.7
Operated side		
Right	611	51.9
Left	568	48.1
Shunt		
Yes	283	24.0
No	896	76.0
Standard endarterectomy	1118	94.8
Eversion endarterectomy	61	5.2
Carotid closure for standard CEA		
Polyester patch	476	42.6
Polyurethane patch	631	56.4
Primary closure	11	1.0
Internal carotid artery – tacking sutures		
Yes	203	17.2
No	976	82.8
Common carotid artery – tacking sutures		
Yes	935	79.3
No	244	20.7
External carotid artery		
Feathered end point at its origin	251	21.3
Section of the plaque at its origin	516	43.7
Eversion endarterectomy	412	35.0

ICA: Internal carotid artery, CCA: Common carotid artery, ECA: External carotid artery.

least 1 week before surgery. All patients were given general anaesthesia, and attempts were made to maintain systolic blood pressure above 140 mmHg during carotid artery cross clamping. All patients received intravenous heparin 50–70 IU kg^{-1} 5 min before clamping. Half of this dose was repeated in patients who needed a surgical revision. Protamine was not administered at the end of the procedure.

Surgical technique

CEA was performed by a senior vascular surgeon ($N = 812$, 68.8%) or by a trainee ($N = 367$, 31.2%) with a senior as first assistant. All procedures were performed using magnification loops. On the CCA, at the proximal end of the endarterectomy, feathering was uncommon and the plaque was usually cut, leaving a small step. If the plaque was not adherent, a few U-shaped stitches were used to affix this flap securely to the artery. The endarterectomy was then carried to the ICA, trying to avoid any step at its distal end. Concerning the ECA, all efforts were made to obtain a feathered end point at its origin ($N = 51$, 21.3%). If unsuccessful, the intima was sectioned at the origin of the ECA with the use of tacking stitches ($N = 516$, 43.7%). If a large atheromatous lesion was protruding into the ECA, eversion endarterectomy of the ECA was performed ($N = 412$, 35.0%). The ECA specimen was measured and checked for distal plaque fracture. Repair was not attempted at this point, but rather upon seeing the results of the completion angiography.

In this series, a shunt was used on a selective basis in 283 patients (24%) in any of the following conditions: occlusion or stenosis >70% of the contralateral carotid artery ($N = 224$), poor backflow from the ICA ($N = 13$) or operation within 7 days following a stroke ($N = 46$). Conventionally accepted methods of determining the need for shunt insertion including electroencephalography (EEG), transcranial Doppler (TCD) or formal measurement of the ICA back pressure were not used. A patch was tailored to restore the normal diameter of the ICA, and was used in all but 11 patients (1%) having a standard endarterectomy. The material used for the patch was polyester (Maquet, SARL, France) in 476 cases (42.6%) or polyurethane (B. Braun, SARL, France) in 631 cases (56.4%).

Completion angiography

Intra-operative angiography was performed after completion of the procedure using an OEC mobile imaging system (General Electrics®) by direct needle puncture and retrograde catheterisation of the CCA with manual injection of 15 ml of contrast media. Two exposures of the carotid bifurcation were obtained with one frontal and one 45° oblique view to avoid the superposition of the ICA and ECA. A third angle was obtained to analyse the cerebral vessels. A videodisc recorder was used to acquire the image sequence and "freeze-frame" the best images for further analysis.

The angiography was examined immediately by the operating surgeon, and the decision to perform a surgical revision was taken according to predefined criteria discussed and approved by the authors after a critical review of the literature[8,9,13,14] in any of the three following situations:

- a residual stenosis of more than 50% of the ICA or CCA and of more than 70% of the ECA;
- any flap; and
- any intraluminal-filling defect.

All these defects were corrected and the angiography was then resumed. Minor defects ($N = 39$) including patch or arterial wall irregularities were ignored. All patients had a duplex scan and an independent neurological evaluation before leaving the hospital, followed by a clinical evaluation with a duplex scan of the carotid arteries on a yearly basis. Median follow-up was 7 years (interquartile range 4.3–9.7 years). Thirty-two patients (3.0%) were lost to follow-up. The major end points of the study were the incidence and type of technical defects, and the 30-day carotid occlusion and stroke rates. During follow-up, any ipsilateral stroke, ipsilateral carotid occlusion or restenosis (>50%) was recorded.

Statistical analysis

Continuous data were expressed as mean ± standard deviation, or median and interquartile range in the event of non-normal distribution. Categorical data were analysed by the chi-square test. Odds ratios (ORs) with 95% confidence interval (CI) were calculated. The incidence of restenosis or occlusion of the CEA was calculated by life-table methods with comparisons made using the log-rank test.

The effect of the various variables on the occurrence of defects, as seen on completion angiography, was studied by univariate analysis. Univariate predictor variables with $p < 0.10$ were entered in a multivariate analysis using a stepwise descending method. A Hosmer–Lemeshow goodness-of-fit test confirmed the model. Logistic regression data were presented as OR with 95% CI. Statistical significance was defined as $p < 0.05$. The statistical analysis was conducted using the Statistical Package for Social Sciences (SPSS) v.18.

Results

Completion angiography

Carotid defects as seen on completion angiography are listed in Table 2. Defects were found in 72 CEAs (6.1%). No complication in relation to carotid catheterisation or injection of contrast media occurred in this series.

No defects or minor abnormalities were seen in 1107 CEAs (93.9%) including 33 (2.8%) transient spasm of the ICA distal to the endarterectomy site (Fig. 2), 16 of them occurring in patients who received a shunt during the procedure. As seen on repeat angiogram, all these spasms regressed after topical use of papaverine (60 mg) or diltiazem (10 mg). We wait 10 min after application of the drug before proceeding to the final angiography.

In this series, seven patients had a stenosis of the ipsilateral intracranial carotid artery of more than 50%. No adverse event occurred in these asymptomatic patients who were not considered for angioplasty.

Table 2 Results of completion angiography in 1179 carotid endarterectomies.

	N	%
No significant defects[a]	1107	93.9
Defects requiring revision	72	6.1
ECA flap[b]	30	2.5
ICA Filling defect[c]	7	0.6
ICA flap	8	0.7
ICA remaining plaque	12	1.0
CCA flap/plaque	15	1.3

ICA: Internal carotid artery, ECA: external carotid artery, CCA: Common carotid artery.

[a] Including 33 patients with a distal ICA spasm related to clamping or shunt insertion that resolved after topical use of papaverine or diltiazem.

[b] Including 6 patients having an ECA flap with a thrombus protruding into the ICA.

[c] Thrombus on the carotid patch.

Abnormal completion angiography ($N = 72$)

ECA ($N = 30$)

The most common site for defect was the ECA with a distal intimal flap (Fig. 3) in 30 cases (2.5%). In six of these cases (0.5%), the intimal flap was associated with a fresh thrombus occluding the ECA and extending partly into the ICA. Among these 30 defects, 22 occurred in 412 eversion endarterectomies of the ECA (5.3%), and eight defects (1%) occurred in 767 procedures with a feathered end point, or section of the plaque with tacking sutures at the orifice of the ECA ($p = 0.01$, OR: 5.3; CI: 2.3–12.3). To correct these defects, a vascular clamp was placed at the origin of the ECA leaving the ICA open, and a separate arteriotomy was made in the ECA to affix the distal intima with tacking sutures. Transverse arteriotomy of the ECA was closed primarily, and longitudinal arteriotomy was closed with a patch. In the six cases presenting with a thrombus extending from the ECA into the ICA, the carotid bifurcation required clamping with re-opening of the ICA patch for complete thrombus removal and correction of the intimal flap on the ECA by a separate arteriotomy with the use of tacking stitches.

ICA ($N = 27$)

An intimal flap was seen at the distal end of the endarterectomy on the ICA in eight patients, who had a patch and no tacking sutures (0.7%), and was corrected by re-opening the ICA with the use of tacking stitches. A thick remaining plaque >50% extending in the ICA above or at the level of the digastric muscle was seen in 12 cases (1%), and was corrected by the use of a polytetrafluoroethylene (PTFE) bypass graft between the CCA and distal ICA. In addition, a non-occlusive thrombus, appearing as a filling defect, was found on the surface of the carotid patch with no other abnormality, in seven patients (0.6%).

CCA ($N = 15$)

A flap or a significant step at the proximal end point of the endarterectomy was seen in 15 cases (1.3%) and was corrected by further resection of the plaque and tacking stitches.

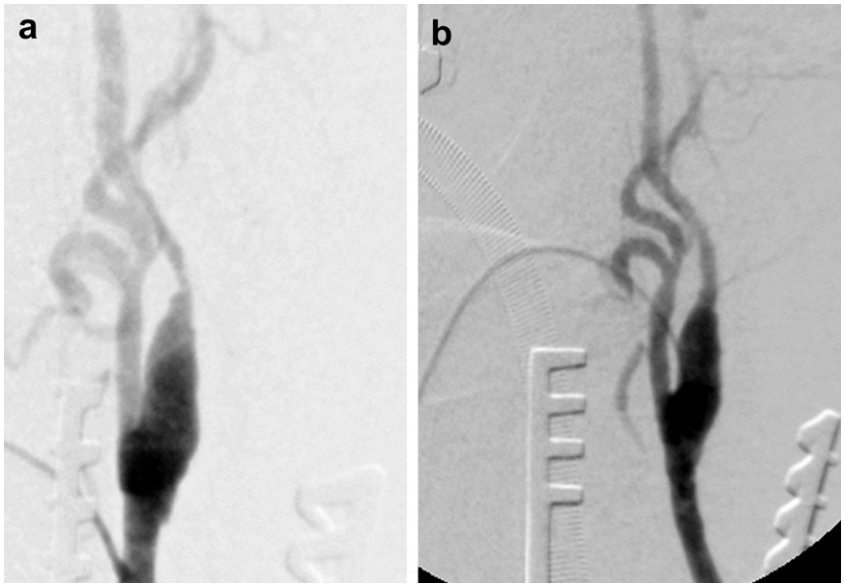

Figure 2 (a) Intraoperative completion angiography showing a significant spasm in the distal internal carotid artery. (b) The spasm was released with the local use of diltiazem; no re-opening was necessary in any of these cases.

Logistic regression analysis (Table 3) showed that total length of the carotid plaque >6 cm ($p = 0.02$, OR: 2.3; 95% CI (1.2—3.7)), eversion endarterectomy of the ECA ($p = 0.01$, OR 3.4; 95%CI (2.1—5.9)) and trainee as first operator ($p = 0.02$, OR 2.4; 95%CI (1.8—4.2)) were independent predictors of operative defects seen on completion angiography.

30-Day postoperative results

For the entire series (Table 4), the 30-day death and stroke rate was 1.5%, with no significant difference among trainees and senior surgeons. Three major strokes were fatal. There was no significant difference ($p = 0.23$, OR: 2.4, 95%CI: 0.5—10.8) when comparing the stroke rate in patients with normal completion angiography (0.2%) to that of the patients with a defect corrected (2.7%); however, there was a significant increase of postoperative transient ischaemic attack (TIA) in the group with revision ($p = 0.001$, OR: 5.8, 95% CI: 1.8—18.9). In this group, all TIAs but one occurred immediately or within 3 h after surgery. Cervical haematoma was also significantly more frequent in patients with revision compared with the patients with normal completion studies ($p = 0.006$, OR:

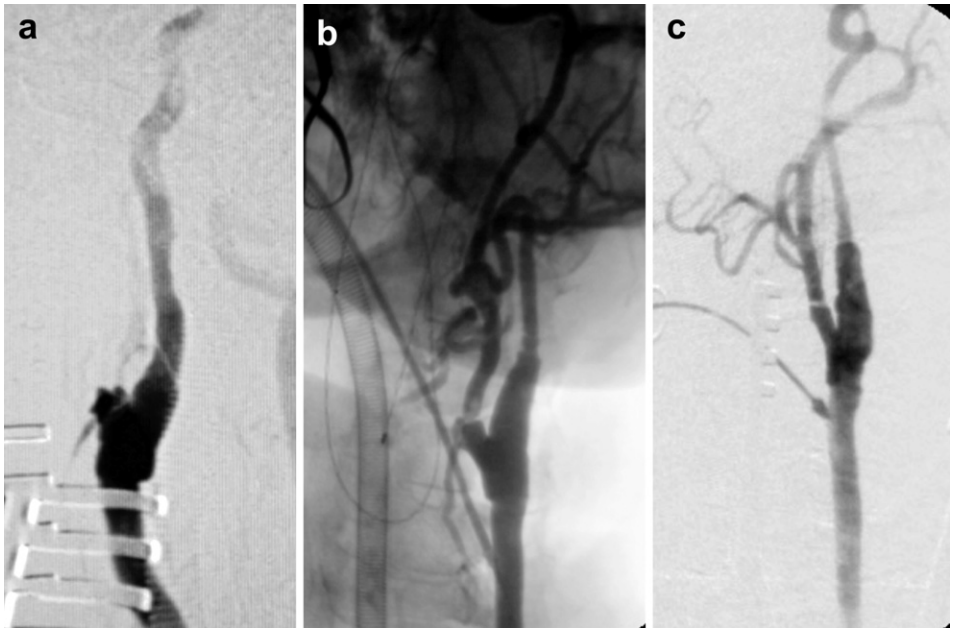

Figure 3 Intraoperative completion angiography showing three different types of defect in the external carotid artery (ECA) after carotid endarterectomy with one complete occlusion, one intimal flap with a thrombus, and one isolated flap. All occurred in three cases of eversion endarterectomy of the ECA.

Table 3 Operative processes and characteristics of carotid lesions with defects found on completion angiography.

		Univariate analysis		Multivariate analysis	
Technique	*N*	Odds ratio [CI]	*p* value	Odds ratio [CI]	*p* value
Standard endarterectomy	1118	1.40 [0.54–3.61]	0.42		
Eversion endarterectomy	61				
Standard endarterectomy closure					
Prosthetic patch	1107	1.45 [0.18–11.56]	0.52		
Primary closure	11				
Shunt					
Yes	283	1.14 [0.66–1.96]	0.67		
No	896				
Length of the plaque (ICA + CCA)					
<6 cm	858	3.46 [2.13–5.60]	0.001	2.31 [1.21–3.72]	0.02
≥6 cm	321				
Internal carotid artery – tacking sutures					
Yes	203	1.66 [0.95–2.89]	0.07	1.21 [0.78–3.13]	0.10
No	976				
ECA – plaque (length)					
<3 cm	1041	1.91 [1.03–3.53]	0.05	1.42 [0.78–3.53]	0.09
≥3 cm	138				
ECA					
Section of the plaque at its origin or feathered end point	767	5.35 [2.36–12.13]	0.001	3.41 [2.10–5.94]	0.01
Eversion endarterectomy	412				
CCA – tacking sutures					
Yes	935	1.63 [0.96–2.79]	0.07	1.2 [0.75–3.2]	0.12
No	244				
First operator					
Senior vascular surgeon	812	1.84 [1.13–2.98]	0.01	2.42 [1.81–4.23]	0.02
Trainee supervised	367				

ICA: Internal carotid artery, ECA: external carotid artery, CCA: Common carotid artery.
The effect of the various variables on the occurrence of defects as seen on CA was studied by univariate analysis. Univariate predictor variables with $p < 0.10$ were entered in a multivariate analysis using a stepwise descending method. Data are presented as odds ratio with 95% confidence interval. Statistical significance was defined as $p < 0.05$. Statistical analysis showed that a plaque of more than 6 cm in length in the internal and common carotid artery, eversion endarterectomy of the ECA, or trainee as first operator were independent predictors of operative defects seen on completion angiography.

11.9, 95% CI: 2.6–54.6). Details concerning patients' characteristics, carotid lesions and operative processes with the associated 30-day stroke rate are shown in Table 5.

Results of postoperative duplex scan are detailed in Table 6. ICA occlusions were seen in three patients with a normal completion angiography (0.27%) and in one patient (1.38%) with a defect corrected after completion angiography ($p = 0.22$, OR: 0.19; 95% CI: 0.02–1.99).

Long-term results

Freedom rate for restenosis (>50%) or occlusion of the ICA/CCA was 92.0 ± 5.4% at 7 years, with no significant difference between the patients with a normal completion angiography (87.5 ± 6.7%) and those with a defect corrected after completion angiography (96.0 ± 9.1%). ICA restenosis occurred in 23 patients (1.9%) and CCA restenosis in 15 patients (1.3%). There were six late strokes, including two ipsilateral strokes, which were related to occlusion of the operated carotid artery.

ECA restenosis >50% or occlusion occurred in 60 patients (5.6%) despite correction of an initial defect in 12 of them. No stroke or TIA occurred in these patients. In total, 126 patients (12.0%) died during follow-up, mainly from myocardial infarction.

Discussion

Because most complications of CEA are technical in nature,[17,18] it makes sense to ensure the effectiveness of the procedure upon its completion. In this study, completion angiography identified 27 critical residual defects in the ICA (2.3%), 15 in the CCA (1.3%) and 30 in the ECA (2.5%). They were all significant with flap, thrombus or loose atheromatous remains, which are a potential source of cerebral embolism.[19] In addition, 33 spasms of the ICA (2.8%) that could have been harmful were relieved by intra-adventitial and topical papaverine infiltration. We have shown in this study that completion angiography was an accurate method of assessing the technical adequacy of CEA, and as the series progressed, these findings helped us to improve our surgical technique. We became more aggressive in the stitching of the sectioned intima of the CCA and extending the endarterectomy proximally on the CCA to avoid any significant step. We were also more

Table 4 30-day mortality and morbidity in 1055 patients having 1179 carotid endarterectomies.

	All procedures $n = 1179$	No defect $n = 1107$	Defect repaired $n = 72$	p	Odds ratio	Odds ratio 95% CI
Stroke[b]	15 (1.2%) (3[a])	13 (0.2%)(2[a])	2 (2.7%)(1[a])	0.23	2.4	0.5—10.8
Death (all)	5 (0.4%)	4 (0.3%)	1 (1.4%)	0.27	3.8	0.4—35.2
TIA[c]	15 (1.2%)	11 (0.9%)	4 (5.5%)	0.001	5.8	1.8—18.9
Death and stroke	17 (1.5%)	15 (1.4%)	2 (2.8%)	0.27	2.0	0.4—9.3
Carotid occlusion	4 (0.3%)	3 (0.3%)	1 (1.4%)	0.22	5.2	0.5—50.5
Cervical hematoma	7 (0.6%)	4 (0.3%)	3 (4.2%)	0.006	11.9	2.6—54.6
Myocardial infarction	6 (0.5%)	5 (0.4%)	1 (1.4%)	0.31	3.1	0.3—26.9
Facial nerve injury	4 (0.3%)	4 (0.3%)	0 (0%)	1	1.7	0.1—31.7
Hypoglossal nerve injury	4 (0.3%)	3 (0.2%)	1 (1.4%)	0.22	5.2	0.5—50.5
Recurrent nerve injury	11 (0.9%)	9 (0.8%)	2 (2.8%)	0.14	3.5	0.7—16.4

TIA: transient ischemic attack.

[a] Fatal strokes. Comparison of procedures without defect after completion angiography with procedures with a defect repaired after completion angiography. Results are presented as numbers, percentages and odds ratio with 95% confidence interval (CI).

[b] 10 strokes were intra-operative, apparent upon recovery from anesthesia 5 were postoperative (2 h, 3 h, 4 h, 6 h, 26 h).

[c] 9 TIA were intra-operative, and 6 occurred within 8 h after surgery.

careful with the ECA in which a defect occurred in 30 patients (3.0%), with a thrombus bulging into the ICA in six patients. We believe, with others,[9,20] that the ECA is a potential site of thrombus formation with the risk of embolic stroke. But we observed in this series that the majority of defects in the ECA occurred in patients having an eversion endarterectomy of the ECA. In comparison, section of the plaque at the origin of the ECA or feather off the origin of the ECA resulted in a significantly lower incidence of ECA defect. In addition, even when revised successfully, these severely obstructed ECAs had a poor long-term patency, with a 40% rate of restenosis or occlusion comparable to that of 45.9% observed by Archie.[21] Given these results, and as recommended by Ascher et al.,[16] we decided to avert, as much as possible, any attempt at external CEA and transect the plaque at the origin of the ECA with the use of tacking stitches. In this aspect also, completion angiography was an accurate method to assess and to improve our technique.

As shown by binary logistic regression analysis, extensive carotid lesions with a carotid plaque extending more than 6 cm in length and eversion endarterectomy of the ECA were independent predictors of the occurrence of technical defects even in well-trained hands. In addition, and independently from the characteristics of the carotid lesion, trainee as first operator was also an independent predictor of technical defect, suggesting that completion angiography should be considered as a routine quality-control procedure for trainees.

But, if completion angiography makes sense, immediate revision could prove risky, as we observed in this group of patients an increased risk of TIA and cervical haematoma. These findings, with those of other authors,[5,6] explain why the ability of these completion studies to actually improve perioperative outcomes after carotid surgery remains controversial.

In a retrospective study, Courbier et al.[13] compared the results of 206 CEAs performed without completion angiography with 100 subsequent CEAs performed with completion angiography and observed a non-significant reduction of the 30-day death and stroke rate from 4.8% to 1% ($p = 0.10$).

Donaldson et al.[9] reported a 16% revision rate, a 1.7% stroke rate and a 0.7% mortality rate after CEA with the use of routine completion angiography, and concluded without any control group that completion study contributed to their low rates of perioperative complications.

Roon and Hoogerwerf[8] compared 157 CEAs without completion angiography with 535 CEAs with completion angiography. The combined stroke and death rate was 4.5% in the control group and 1.3% in the group with completion angiography ($p < 0.01$). However, there were more symptomatic patients in the control group (19.8%) than in the group with completion angiography (13.5%, $p = 0.05$). Woeffle et al.[22] compared, in a prospective study, 115 CEAs performed with completion angiography with 116 CEAs without completion angiography, and demonstrated no significant difference in the 30-day death and stroke rates.

Other authors have also studied the value of duplex scan as an alternative to completion angiography to assess the technical result of CEA. Kinney et al.,[23] in a series of 461 CEAs, detected severe residual flow abnormalities in 26 (5.6%) CEAs. Immediate revision was performed without an adverse event in 25 patients, but resulted in a stroke in one revised reconstruction. Lennard et al.[14] reported that a policy of transcranial Doppler and angioscopy has also contributed to a reduction of intra-operative stroke following CEA. In this series, no intra-operative stroke occurred, but the rate of postoperative stroke was 2.8%. Recently, Ascher et al.[16] reported the results of intra-operative duplex scanning in a series of 650 consecutive primary CEA procedures with a combined mortality and stroke rate of 0.8%. In this series, 15 major defects (2.3%) were identified and successfully repaired. No patient who underwent revision had a postoperative stroke. These studies suggest that routine intra-operative assessment of CEA by duplex scan decreases the risk of postoperative stroke. However, its use has been limited by the need for equipment and by the technical expertise required in the operative room to perform and interpret the study.

Recently, Pratesi et al.[6] recommended a balanced policy of selective completion angiography at the surgeon's discretion. They compared, in a single centre, 430 patients

Table 5 Patients characteristics, carotid lesions and operative processes with associated 30-day stroke rate.

	N	Stroke rate (%)	*p* value
Age (y)			
<70	580	1.72	0.44
≥70	475	1.05	
Gender			
Male	728	1.24	0.57
Female	327	1.83	
Current smoker			
Yes	696	1.58	0.78
No	359	1.11	
Hypertension			
Yes	685	1.31	0.78
No	370	1.62	
Congestive heart failure			
Yes	61	4.92	0.05
No	994	1.21	
Coronary artery disease			
Yes	221	2.26	0.21
No	834	1.20	
Unstable angina			
Yes	45	6.67	0.02
No	1010	1.19	
Peripheral arterial disease			
Yes	295	1.69	0.58
No	760	1.32	
Diabetes mellitus			
Yes	232	2.59	0.11
No	823	1.09	
Renal insufficiency			
Yes	57	1.75	0.57
No	998	1.40	
Surgical indications			
Transient ischemic attack	318	0.94	0.01
Stroke	185	3.78	
Asymptomatic	552	0.91	
Ipsilateral stenosis			
50–69%	212	1.89	0.33
70–99%	967	1.14	
Contralateral stenosis			
<60%	825	0.97	0.16
60–99%	354	1.98	
Technique			
Standard endarterectomy	1118	1.25	0.55
Eversion endarterectomy	61	1.64	
Carotid closure			
Polyester patch	476	1.05	0.47
Polyurethane patch	631	1.27	
Primary closure	72	2.78	
Shunt			
Yes	283	1.77	0.37
No	896	1.12	
Length of the carotid plaque			
<6 cm	858	0.93	0.14
≥6 cm	321	2.18	
ICA – tacking sutures			
Yes	203	1.97	0.30
No	976	1.13	
ECA			
Section of the plaque or feathered end point at its origin	767	1.04	0.41
Eversion endarterectomy	412	1.70	
CCA – tacking sutures			
Yes	935	1.07	0.21
No	244	2.05	
First operator			
Senior vascular surgeon	812	1.35	1.00
Trainee supervised	367	1.09	

ICA: Internal carotid artery, ECA: External carotid artery, CCA: Common carotid artery. The 30-day death and stroke rates are compared using the Fisher's exact test. Statistical significance is defined as $p < 0.05$.

who had a routine completion angiography with 484 patients with selective completion angiography in 48 of them. The decision to proceed with completion angiography and to revise was left to the surgeon's discretion without predefined criteria. The 30-day combined death and stroke rate was 1.9% for patients with routine completion angiography as compared with 1.4% for patients with selective completion angiography. The authors suggest that routine completion angiography was useful only in some difficult situations and for less-experienced surgeons. One review of this study mentions the lack of definition for the defects that required immediate revision. This brings the issue of introducing quality control in carotid surgery, with objective criteria for revision. We considered in our study that it was essential in a teaching hospital to set up guidelines to assess the effectiveness of CEA including predefined criteria for revision. We used intra-operative angiography because it was quick, safe and produces excellent images without the need for any specific added expertise.

However, perhaps the challenge lies in the details, and Zannetti et al.[5] brought up another concern by reporting a subgroup analysis of 1305 (EVEREST) patients[24] subjected to an intra-operative completion study. Overall, 112 defects (9%) were identified and 48 (4%) were revised. Logistic regression analysis showed that carotid plaque extension >2 cm on the ICA was a positive independent predictor of CEA defects (OR, 1.5; $p = 0.03$). In this series, the 30-day combined death and stroke rate was low (1.6%), but the postoperative stroke rate was 14.3% (5/35) for patients requiring correction for ICA and CCA defects, compared with 1.4% (17/1193) for patients whose intra-operative control was normal ($p = 0.0002$). This striking difference could be related to the greater complexity of revising an eversion endarterectomy that sometimes requires conversion to a bypass or to a standard CEA with patching, adding more prolonged cerebral ischaemia. In our series, we did 61 eversion CEAs and two redo procedures for a flap on the CCA that was corrected by further resection of

Table 6 30-day postoperative carotid duplex imaging in 1055 patients having 1179 carotid endarterectomies according to the results of intra-operative completion angiography.

	Normal completion angiography $n = 1107$ (%)	Abnormal completion angiography $n = 72$ (%)	p	Odds ratio	Odds ratio 95% CI
ICA occlusion	3 (0.27)	1 (1.38)	0.22	0.19	0.02—1.99
ECA occlusion	3 (0.27)	1 (1.38)	0.22	0.19	0.02—1.99
ECA stenosis >50%	16 (1.47)	1 (1.40)	1.00	1.04	0.13—7.96

Results are presented as numbers, percentages and odds ratio with 95% confidence interval (CI). ICA: Internal carotid artery, ECA: External carotid artery.

the carotid plaque and tacking stitches. This was an uneventful and quick procedure. In the Zannetti study, the decision to revise was left to the discretion of the surgeon with no predefined criteria and only 43% of the defects were corrected, making the interpretation of these results difficult. In addition, this subgroup analysis was not pre-specified in the protocol of the EVEREST study, and could have lead to overstated and misleading results.[25] Other authors[16,26—30] before us have shown that completion angiography and revision can be done without significantly increasing the risk of stroke, but we have observed an increased risk of TIA in these patients. The reason why this happens remains unclear. It is impossible to establish in these patients operated under general anaesthesia a temporal relationship between the onset of TIA, CEA, completion angiography and revision. It is possible that some of these patients had an immediate cerebral embolism when flow was initially resumed in the ICA, and this cannot be prevented by completion angiography. In addition, reclamping, which increases the duration of cerebral ischaemia can also be harmful. However, it seems logical to expect that immediate correction of a technical defect would limit the risk of further cerebral embolism and stroke.

Even if our findings give strong arguments in favour of the use of intra-operative completion angiography and confirm previous reports,[8,9,13,26,31] the lack of a randomised controlled trial (RCT) contributes to the doubt as to whether it confers any overall benefit. However, it is unlikely that the effectiveness of intra-operative assessment can be proven by an RCT. This is first because of the low stroke rate associated with CEA, necessitating a large number of patients, and second, because to identify which defects should be corrected, there would need to be a group of patients in whom a defect detected would be left uncorrected, and this would raise obvious ethical issues. The last option is an RCT between imaging and no imaging that would include the potential risk of the completion study in the analysis.

Conclusions

In our centre, CEA with routine completion angiography resulted in good perioperative outcome. Plaque length, technique for ECA endarterectomy and trainee as first operator were independent predictors of operative defects seen on completion angiography.

Conflict of Interest/Funding

None

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